

## ORION EXPLORATION FLIGHT TEST POST-FLIGHT INSPECTION AND ANALYSIS

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## ABSTRACT

### Introduction

The multipurpose crew vehicle, Orion, is being designed and built for NASA to handle the rigors of crew launch, sustainment and return from scientific missions beyond Earth orbit. In this role, the Orion vehicle is meant to operate in the space environments like the naturally occurring meteoroid and the artificial orbital debris environments (MMOD) with successful atmospheric reentry at the conclusion of the flight. As a result, Orion's reentry module uses durable porous, ceramic tiles on almost thirty square meters of exposed surfaces to accomplish both of these functions. These durable, non-ablative surfaces maintain their surface profile through atmospheric reentry; thus, they preserve any surface imperfections

that occur prior to atmospheric reentry. Furthermore, Orion's launch abort system includes a shroud that protects the thermal protection system while awaiting launch and during ascent. The combination of these design features and a careful pre-flight inspection to identify any manufacturing imperfections results in a high confidence that damage to the thermal protection system identified post-flight is due to the in-flight solid particle environments. These favorable design features of Orion along with the unique flight profile of the first exploration flight test of Orion (EFT-1) have yielded solid particle environment measurements that have never been obtained before this flight.

The EFT-1 mission took the reentry vehicle through two orbits of the Earth with the first orbit achieving an apogee of approximately 1000 km and a second orbit apogee of just under 6000 km as illustrated by the blue flight profile curve in Fig. 1. In this figure the mission timeline runs along the abscissa, and the vehicle altitude is shown along the left hand ordinate. As can be seen, in the figure this flight profile took Orion beyond the inner Van Allen radiation belts and had a very high reentry speed representing realistic, stressing conditions for the vehicle from the natural environment; however, the radiation and high heating reentry were not the only stressing conditions experienced by Orion on this test flight. As a result of spending a significant fraction of time in some of the worst bands of the artificial environment of orbital debris, the EFT-1 represented a unique observation of the nature of this environment.

The predicted orbital debris environment from the recently developed NASA orbital debris engineering model, ORDEM3.0, is also shown in Fig. 1 as a black curve where the EFT-1 flux of 1 mm solid particles and greater are normalized to the flux at 400 km as related to the altitude, which is representative of the operational altitude of the International Space Station. As can be seen that the predicted flux on the reentry vehicle approached thirty-five times that at the ISS near the apogee of the first orbit, which EFT-1 subsequently visited two

more times on the second orbit. This EFT-1 trajectory coupled with the structure of the Orion thermal protection system results in the first ever direct measurements of the worst debris bands surrounding Earth from a large returned surface.

The principal mechanism for developing orbital debris environment models, is to make observations of larger pieces of debris in the range of several centimeters and greater using radar and optical techniques. For particles that are smaller than this threshold, breakup and migration models to return surfaces in lower orbit are relied upon. This reliance on models to derive spatial densities of particles that are of critical importance to spacecraft make the unique nature of the EFT-1's return surface a valuable metric. To this end detailed post-flight inspections identified six candidate impact sites present on the returned capsule that were not present during the pre-flight inspections. These candidate impact sites, shown in Fig. 2, are scattered about the Orion reentry backshell and ranged from approximately a half millimeter in diameter to about two millimeters in diameter. This paper describes the EFT-1 mission, the ground based testing to understand small particle craters, the pre- and post-flight inspection, and the crater analysis for environment information from this unique returned sample.

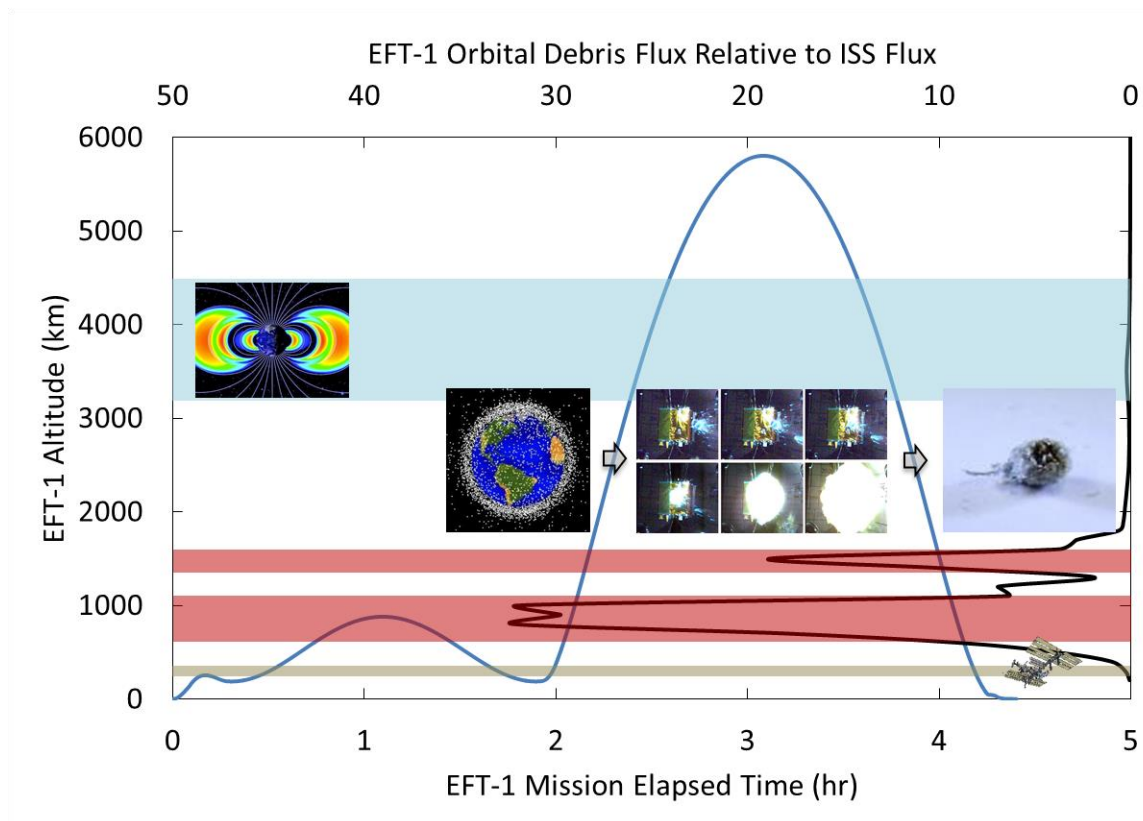


Fig. 1 Orion's EFT-1 flight profile (blue curve) relative to debris environment (black curve)

### EFT-1 Post-Flight MMOD Inspection Results

Possible 6 MMOD impacts found on Orion tiles post-flight, 5 of which are >0.5mm deep

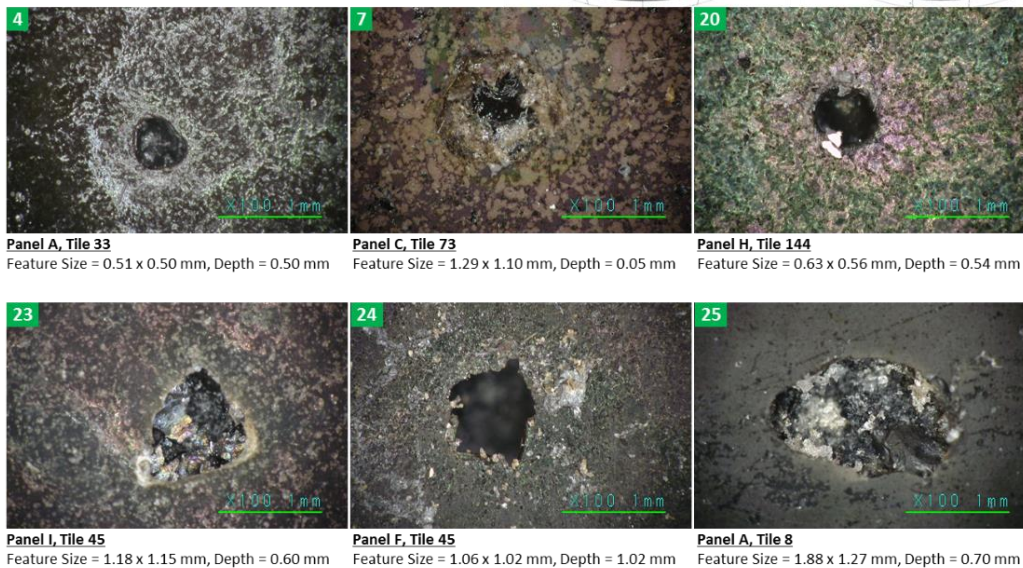
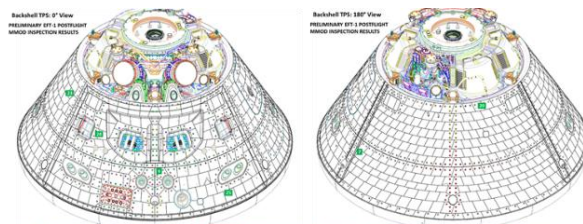


Fig. 2 Six candidate impact craters from EFT-1 post-flight inspection results